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Global burden attributable to high sodium intake from 1990 to 2019

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Abstract *Background and aims:* High sodium intake is associated with a higher risk of a wide range of diseases. We aimed to estimate the pattern and trend of the global disease burden associated with high sodium intake from 1990 to 2019.
Methods and results: We obtained numbers and rates of death and disability-adjusted life year (DALY) attributable to high sodium intake by sex, socio-demographic index, and country from the Global Burden of Disease Study 2019. We calculated the estimated annual percentage change to evaluate the age-standardized rate (ASR) of the burden attributable to high sodium intake between 1990 and 2019. We further calculated the contribution of population growth, population aging, and age-specific rates of death and DALY to the net change in the total number of deaths and DALYs attributable to high sodium intake. From 1990 to 2019, global age-standardized rates of death and DALY attributable to high sodium intake substantially decreased for both sexes. However, there were significant increases in the total numbers of deaths and DALYs attributable to high sodium intake, which were driven by population growth and population aging. The attribution of population growth and population aging varied widely across countries, with a higher contribution of population growth in most developing countries and a higher contribution of population aging in countries with slow population growth.
Conclusions: Although the global burden attributable to high sodium intake in terms of age-standardized rate declined from 1990 to 2019, the absolute burden increased significantly, which was driven by population growth and population aging.

Introduction

High sodium intake is associated with adverse health outcomes [1,2]. Epidemiological studies and clinical trials have provided compelling evidence that high sodium intake can raise blood pressure, increasing the risk of cardiovascular disease [3–9]. Conversely, a reduction in sodium intake decreases blood pressure levels and the

Abbreviations: GBD, Global Burden of Disease; DALY, Disability-adjusted Life Year; SDI, Socio-demographic Index; EAPC, Estimated Annual Percentage Change; SEV, Summary Exposure Value.

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incidence of hypertension, and cardiovascular morbidity and mortality [2,10,11].

Besides cardiovascular diseases, high sodium intake was also associated with an increased risk of kidney disease [12,13] and stomach cancer [14,15]. Given that the world is facing a growing and aging population and that most diseases associated with high sodium intake are age-related [16], the burden attributable to high sodium intake is likely to increase.

Understanding the global burden attributed to high sodium intake and its temporal trends and exploring which factors drive these trends can provide evidence for policymakers to develop tailored programs or legislations to reduce sodium intake. Accordingly, we comprehensively examined the disease burden attributable to high sodium intake using the Global Burden of Diseases (GBD) Study 2019, a multi-national collaborative research study that estimates the disease burden for 204 countries and territories worldwide.

Methods

Study data

We retrieved data from GBD 2019 via the Global Health Data Exchange query tool [17]. We obtained the absolute number, age-standardized and age-specific rate of deaths, and disability-adjusted life-years (DALYs) attributable to high sodium intake between 1990 and 2019 by sex, country, GBD region, and socio-demographic index (SDI) quintile. SDI was calculated by combining the income per capita, education rate, and fertility rate, and then grouped into low, low-middle, middle, high-middle, and high SDI quintiles [18,19]. We also classified countries and territories into 21 geographic regions based on epidemiological similarity and geographical proximity. For example, Japan, South Korea, and Singapore are classified in the high-income Asia–Pacific region. We presented results as numbers and 95% uncertainty intervals (UIs).

Estimation of high sodium intake exposure

High sodium intake assessment has been detailed elsewhere [1,20]. Briefly, sodium intake was measured by 24-h urinary sodium. Levels of sodium intake in each age-sex-location-year were estimated based on all available data sources, such as population-representative survey and surveillance data, using spatiotemporal Gaussian process regression and Disease Modeling – Meta-regression (DisMod-MR). DisMod-MR is an integrative systems modeling approach and was used in the GBD study to quantify deaths from each cause by age, sex, country, and year. GBD ascertained the optimal level of sodium intake corresponding to a minimum stroke risk derived from the meta-analyses of studies examining the association between sodium intake and disease outcomes and weighted by the global proportion of corresponding disease outcomes [4]. The uncertainty of the optimal levels of sodium intake was calculated based on a uniform distribution in uncertainty estimation sampling [20]. As a result, the optimal sodium intake level and its uncertainty is 3 g (95% UI: 1 g, 5 g) per day. High sodium intake was defined as an intake level higher than 3 g per day [21]. We obtained age-standardized summary exposure values (SEVs) for high sodium intake by sex, location, and regions to represent population exposure. SEV is a measure of a population's exposure to a risk factor, which considers the degree of exposure by risk level and the severity of the risk to disease burden [18]. SEV ranges from 0% to 100%, where 0% indicates no one is exposed to high sodium intake in a population, and 100% means that an entire population is exposed to high sodium intake.

Deaths and DALYs attributable to high sodium intake

GBD 2019 estimated attributable deaths, years of life lost (YLLs), years of life lived with disability (YLD), and disability-adjusted life-years (DALYs) for high sodium intake, at the global and regional level, and for 204 countries and territories from 1990 to 2019 [21]. A comparative risk assessment approach was used to estimate the population-attributable fraction for high sodium intake–outcome pair by age, sex, country, and year. The number of deaths and DALYs attributable to high sodium intake was estimated by multiplying the population-attributable fraction by the total number of disease-specific deaths and DALYs [21]. To calculate cardiovascular disease attributable to high sodium intake, the GBD first estimated the association between urinary sodium and changes in systolic blood pressure, and then estimated the relationship between changes in systolic blood pressure and cardiovascular disease. Deaths were defined as the number of deaths occurring in a population during a specific period. DALYs were the sum of YLLs, based on a reference maximum observed life expectancy, and YLDs based on standardized disability weights for each health state. The population-attributable fraction was calculated by using exposure, estimates of relative risk, and theoretical minimum risk level.

Statistical analysis

We used age-standardized rates (ASR) of death and DALY to eliminate the effect of demographic differences. Trends in age-standardized rates were estimated using the estimated annual percentage change (EAPC), which was calculated using a general linear model of age-standardized rates over time [1,22,23]. We fitted the logarithm of age-standardized rates to a regression model: $\ln(\text{ASR}) = \beta_0 + \beta_1 X + \varepsilon$, where X was calendar year, and EAPC can be calculated as $(\exp(\beta_1) - 1) \times 100$ [22]. The age-standardized rate was considered to be increasing if the lower boundary of its 95% confidence

intervals (CIs) was higher than zero. In contrast, if the higher boundary of its 95% CIs was lower than zero, which indicates a decreasing trend for the age-standardized rate. Otherwise, the age-standardized rate was considered to be stable.

Trends in disease burden reflect the changes in the rates of death and DALY and the demography change. We used a recently developed decomposition method [23–25] to decompose the net difference of the absolute numbers of deaths and DALYs attributable to high sodium intake between 1990 and 2019 into the contribution of each of the three factors—population growth, population aging, and age-specific rate of death and DALY, globally and in the 21 GBD regions, with 1990 as the reference year. This decomposition algorithm was highly robust to the choice of the decomposition order and the choice of the reference year. This method has been used to quantify the impact of population aging on mortality for 195 countries or territories and 169 causes of deaths [24], and to quantify the demographic and epidemiologic drivers of the impact of air pollution and high sodium intake [1,23,26]. We performed all statistical analyses using the R software (Version 3.6.2, R core team); a 2-sided p-value < 0.05 was considered statistically significant.

Results

Trend in exposure to high sodium intake

In 2019, global age-standardized SEV for high sodium intake was 50.57 (95% UI: 32.07, 66.99) for males and 39.52 (95% UI: 22.75, 57.37) for females (Supplemental Fig. S1). Global high sodium intake exposure remained virtually unchanged for males and decreased slightly for females from 1990 to 2019.

There was considerable variation in the trend across GBD regions for high sodium intake exposure. High sodium intake exposure declined substantially for both sexes in the high-income Asia Pacific, Southeast Asia, and Central Asia, decreased notably for females in Central Europe. By contrast, it increased in high-income North America and South Asia for males. East Asia had much higher exposure to high sodium intake than other regions, with little change from 1990 to 2019, almost twice the world level.

Global attributable burden for high sodium intake

In 2019, age-standardized rate of death attributable to high sodium intake was 32.96 (95% UI: 9.25, 69.86) per 100,000 population for males and 15.71 (95% UI: 2.58, 39.37) per 100,000 population for females globally (Fig. 1, Supplemental Table S1); global age-standardized rate of DALY attributable to high sodium intake was 760.79 (95% UI: 238.13, 1512.84) per 100,000 population for males and 344.31 (95% UI: 67.66, 826.10) per 100,000 population for females (Supplemental Fig. S2, Table S2). From 1990 to 2019, global age-standardized rate of death attributable to high sodium intake decreased by an average 1.29% (95% CI: 1.25%, 1.32%) per year for males and 1.88% (95% CI: 1.82%, 1.93%) per year for females (Supplemental Table S1); global age-standardized rate of DALY attributable to high sodium intake changed by an average −1.26% (95% CI: −1.30%, −1.22%) per year for males and −1.95% (95% CI: −2.01%, −1.89%) per year for females (Supplemental Table S2).

Regionally, high sodium intake attributable deaths and DALYs decreased in most GBD regions for both sexes (Fig. 1, Supplemental Fig. S2) from 1990 to 2019. The largest decrease occurred in Central Europe for males and Central Europe and East Asia for females. Among males, high sodium intake attributable deaths and DALYs were highest in Central Europe, East Asia, Central Asia, Southeast Asia, and Oceania. For females, high sodium intake attributable deaths and DALYs were highest in East Asia, Eastern sub-Saharan Africa, Southeast Asia, Oceania, Central Europe, and Central Asia. By contrast, high sodium intake attributable deaths and DALYs were lowest in North Africa and the Middle East, Western Europe, and Australasia.

The total number of deaths and DALYs attributable to high sodium intake had risen since 1990, reaching 1.89 (95% UI: 0.48, 4.19) million deaths and 44.87 (95% UI: 13.02, 94.68) million DALYs in 2019, increased by around 0.57 million and 11.48 million, respectively (Supplemental Tables S1 and S2). These increases were net results of large decreases in high-income countries in Europe and the Asia Pacific and large increases in East Asia, Southeast Asia, South Asia, and Oceania (Fig. 2 and Supplemental Fig. S3). The number of deaths and DALYs attributable to high sodium intake more than doubled in South Asia and Oceania, increased by about two-thirds in Southeast Asia, and increased by about one-half in East Asia. In 2019, East Asia, Southeast Asia, and South Asia accounted for more than two-thirds of global deaths and DALYs attributable to high sodium intake.

The disease distribution that contributed to high sodium intake-attributable burden varied by GBD regions (Supplemental Fig. S4). Cardiovascular diseases, including ischemic heart disease, stroke, and hypertensive heart disease, accounted for most of these diseases and a small proportion of chronic kidney disease and stomach cancer.

Impact of demographic change on the burden attributable to high sodium intake

We calculated the contributions of population growth, population aging, and age-specific rate of death and DALY attributable to high sodium intake to the net changes of deaths and DALYs between 1990 and 2019 globally and in 21 GBD regions (Fig. 3, Supplemental Fig. S5, Tables S3 and S4), with 1990 as the reference year. From 1990 to 2019, global high sodium intake attributable deaths increased by more than 560,000, an increase of 42.8% from 1990,

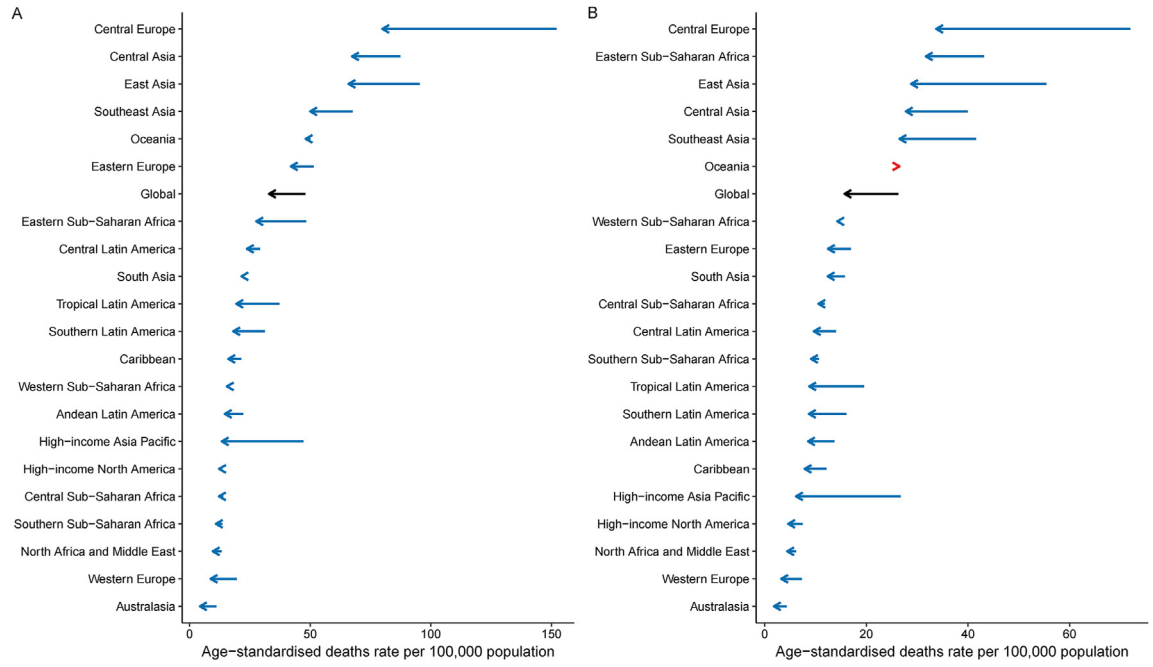

Figure 1 Change in age-standardized rate of death attributable to high sodium intake between 1990 and 2019 globally and in 21 GBD regions for males and females. A, Age-standardized rate of death attributable to high sodium intake for males. **B,** Age-standardized rate of death attributable to high sodium intake for females. The start of the arrow shows the level in 1990, and the head indicates the level in 2019.

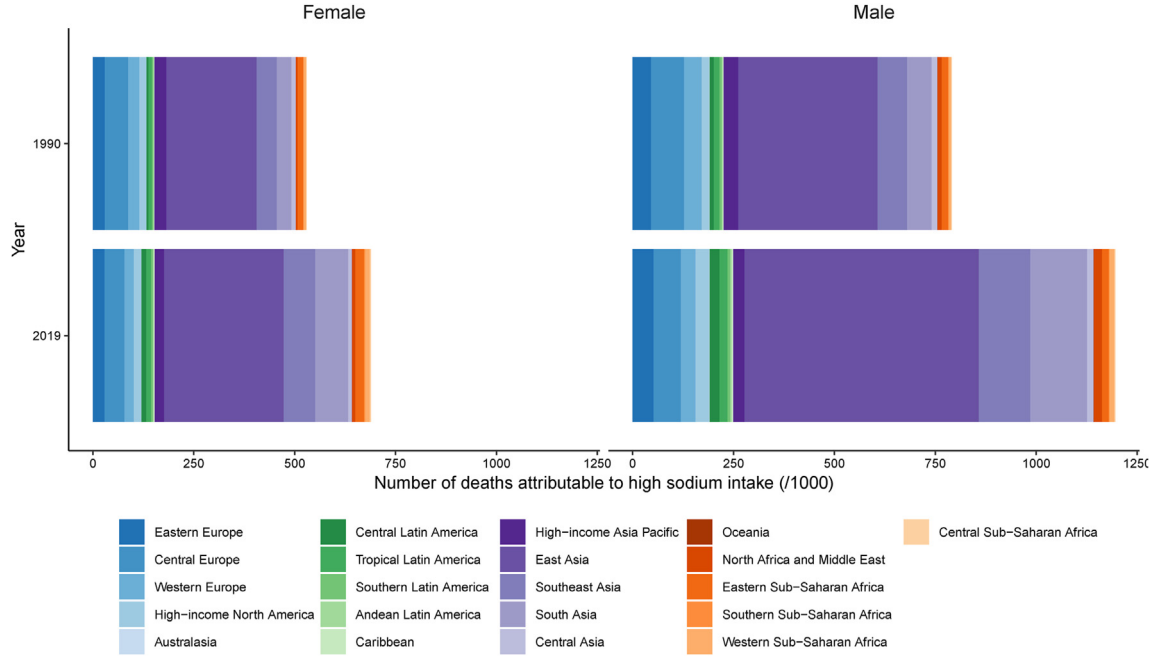

Figure 2 Deaths attributable to high sodium intake by GBD region in 1990 and 2019 for females and males.

despite a decrease of 54.2% in the deaths due to age-specific death rate change. This increase was driven by the change due to population aging (51.4% increase from 1990) and population growth (45.6% increase from 1990).

Most GBD regions experienced declines in the age-specific rate of death and DALY attributable to high sodium intake, except for Oceania. Population aging occurred in most GBD regions except for Western sub-Saharan Africa. Population growth occurred in all GBD regions except for Eastern and Central Europe. Changes in the number of deaths and DALYs attributable to high sodium intake were the combined result of population growth, population aging, and the age-specific rate of high sodium intake attributable death or DALY. Consequently, the combination

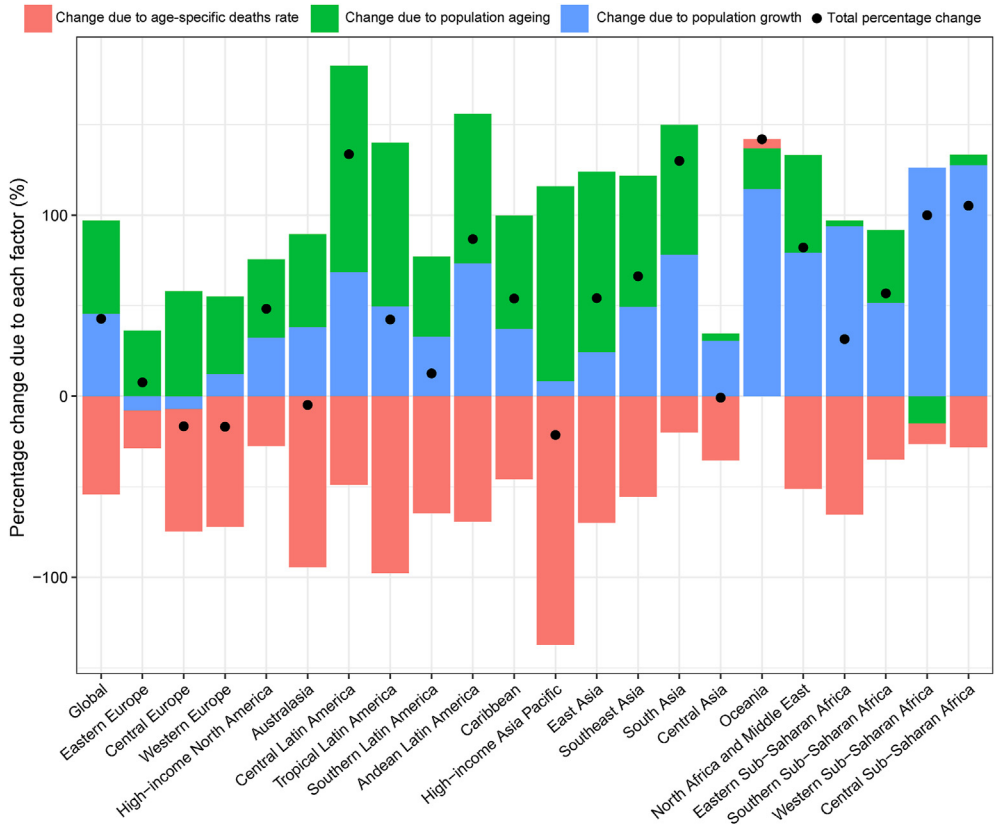

Figure 3 Contribution of changes in population growth, population aging, and age-specific rates of death to changes in deaths attributable to high sodium intake, 1990–2019.

of these three factors resulted in a salient increase in the number of deaths and DALYs attributable to high sodium intake in 16 GBD regions other than Central Europe, high-income Asia Pacific, Western Europe, Central Asia, and Australasia. The contribution of population aging was more pronounced in Central Latin America, high income Asia–Pacific, East Asia, Tropical Latin America, Andean Latin America, Southeast Asia, South Asia, Caribbean, North Africa and the Middle East, and Central Europe, where it exceeded 50%. The contribution of population growth was more notable in Africa, Oceania, Middle East, South Asia, Andean Latin America, and Central Latin America, with more than 50% contribution.

High sodium intake attributable burden by country

There was considerable variation in the attributable burden of high sodium intake across countries. In 2019, the age-standardized rate of death attributable to high sodium intake varied nearly 40-fold across countries (Fig. 4), ranging from 2.56 (95% UI: 0.26, 10.68) in Australia to 102.38 (95% UI: 33.98, 185.04) in North Macedonia. The age-standardized death rates exceeded 60.0 per 100,000 population in North Macedonia, Bulgaria, Serbia, Montenegro, Solomon Islands, Romania, Uzbekistan, and Nauru. In general, countries in Central Europe, the Balkans, East Asia, Southeast Asia, and Central Asia had a higher age-standardized rate of death attributable to high sodium intake. In contrast, countries in Western and Northern Europe, the Americas, Africa, and Australia had a relatively low age-standardized rate of death attributable to high sodium intake.

From 1990 to 2019, South Korea, Japan, Maldives, Singapore, and Ireland had the highest decrease in the age-standardized rate of death attributable to high sodium intake, with more than an average 4.0% decrease per year. In contrast, Pakistan, Nepal, Bhutan, Bangladesh, Ghana, Honduras, Dominican Republic, and Lesotho had the highest increase, with more than an average 1.0% increase per year (Supplemental Fig. S6). Countries with the increased age-standardized rate of death attributable to high sodium intake are mainly located in South Asia and Africa.

Global DALYs attributable to high sodium intake had a similar pattern with deaths attributable to high sodium intake (Supplemental Figs. S5 and S6). In 2019, due to its large population, China had the highest-burden attributable to high sodium intake with more than 850,000 deaths and twenty-one million DALYs, more than four times as many as second-ranked India, followed by Indonesia, Russia, and the United States.

Discussion

We performed a comprehensive estimate of the global spatial pattern and temporal trend in the burden

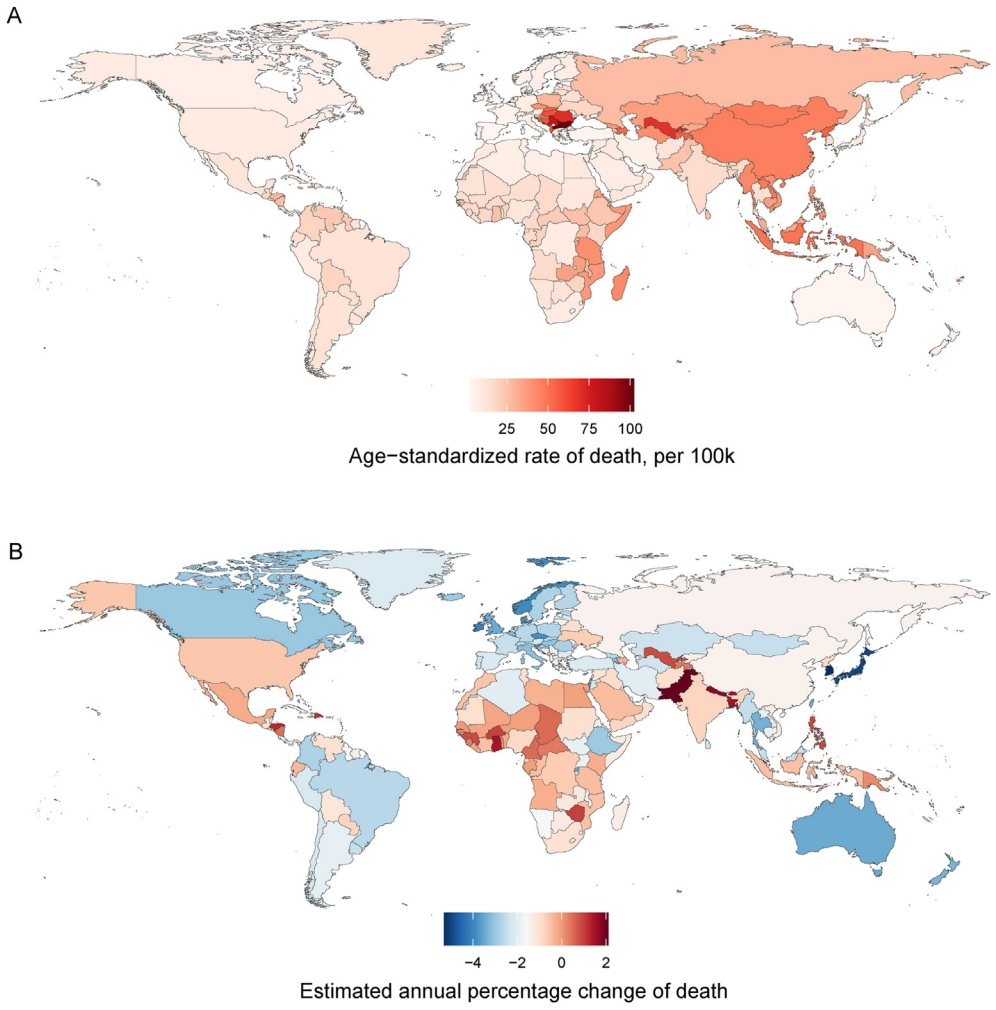

Figure 4 Age-standardized rate of death attributable to high sodium intake and its trends. A, Age-standardized rate of death attributable to high sodium intake by country for both sexes in 2019. **B,** Estimated annual percentage changes in the age-standardized rate of death attributable to high sodium intake by country between 1990 and 2019 for both sexes.

attributable to high sodium intake from 1990 to 2019. Our results showed that a significant decrease in the global burden attributable to high sodium intake in terms of age-standardized rate but a marked increase in the absolute burden. The increase in absolute burden was mainly driven by demographic factors, i.e., population growth and population aging, resulting in some European, Asian, and Oceanian countries having the highest burden attributable to high sodium intake in 2019.

Our analysis showed a general decline in high sodium intake exposure, with the most pronounced decreases in high-income Asia−Pacific, Southeast Asia, and Central Asia. This indicates that global sodium reduction measures may have had a relatively good effect. For example, Japan [27] and South Korea [28] have achieved better results with their sodium reduction measures, but sodium intake still exceeds the WHO recommendation for adults. Particularly unpromising is the fact that high sodium intake exposure remains high in East Asia, Central Europe, and high-income Asia−Pacific, so sodium reduction measures in these regions still need to be pursued. Exposure to high sodium intake is even on the rise in high-income North America and South Asia, suggesting that sodium reduction measures may not be effective in these regions.

Our results showed a general decline in the burden attributable to high sodium intake in terms of age-standardized rate, mainly due to two factors. First, the effectiveness of sodium reduction led to a general decrease in exposure to high sodium intake. Second, the prevention and treatment of diseases associated with high sodium intake, such as cardiovascular disease, gastric cancer, and chronic kidney disease, have been greatly improved in the last three decades, especially in developed countries. However, the absolute burden attributable to high sodium intake is increasing, reflecting the effects of population growth and aging.

Our analysis suggests that epidemiologic changes would reduce the burden attributable to high sodium intake in almost all GBD regions without the effects of population growth and population aging. However, the combined effects of population growth and population aging in most GBD regions could not be offset by

epidemiologic changes. This is particularly true in countries with significant population growth or population aging over the past three decades. China, for example, is the country with the highest burden attributable to high sodium intake despite having a lower age-standardized rate of burden in 2019 than in 1990, because it has experienced significant population growth and aging over the past three decades.

Our study suggests that changes in disease burden attributable to high sodium intake are driven by a combination of three factors: population growth, population aging, and age-specific rate of death or DALY attributable to high sodium intake. For most countries, the effects of population growth and population aging are likely to be more noteworthy. For countries with slow population growth, such as Japan and Poland, the contribution of population aging is more salient. For most developing countries, the contribution of population growth is relatively larger than that of population aging. The contribution of population growth and population aging is significant in some countries, such as China and South Korea, both of which have experienced significant population growth and population aging in the last three decades.

Our analysis complemented the GBD 2017 diet collaborators on the impact of population growth and aging on dietary risk, which proposed that population growth and aging have led to a continued increase in dietary risk burden [20].

The study provides valuable data and insights to guide health policy development and health system reform. There are many national salt reduction initiatives, and region-wide actions launched by a few regional agencies, such as the European Salt Action Network, and the Pan American Health Organization [29]. However, the current average sodium intake of adults in many countries is much higher than the recommended level, especially in East Asian countries and the United States. Our findings of the disease burden associated with high sodium intake might provide some indications of the effectiveness of the ongoing salt reduction initiatives. Considering the varying sources of sodium from country to country, for example, the primary source of sodium is home cooking in China but is food supply in the United States [30], comprehensive sodium reduction measures should continue to be promoted, especially for regions with undesirable sodium reduction. For East Asian countries with rapidly aging populations such as China, Japan, and South Korea, and less developed countries with rapidly growing populations, these countries should allocate health resources to raise awareness and prevention of cardiovascular disease, gastric cancer, and chronic kidney disease, which are closely related to high sodium intake to reduce the high sodium intake attributable burden.

These results need to be considered in light of potential limitations. First, our results depend on the quality of the GBD estimate of high sodium intake attributable burden. However, the high sodium intake exposure data in GBD 2019 include only 92 sources from 53 countries, and the high sodium intake attributable burden data have only 21 sources from 6 countries. Therefore, most countrie's data are modeled by the GBD method, so that the reliability may be insufficient [21]. Second, to estimate the effect of sodium on the cardiovascular outcome, GBD first estimated the relationship between urinary sodium and change in systolic blood pressure and then estimated the relationship between change in systolic blood pressure and cardiovascular outcome, which inevitably increased data uncertainty. Finally, the study is subject to all the general limitations described by the GBD collaboration [21,31], for example, errors in the simulation process and the lack of data in less developed countries, which may affect the accuracy of the estimates.

In conclusion, our study assessed the temporal and spatial variation in the burden attributable to high sodium intake and quantified the impact of demographic changes. Although the global age-standardized rate of burden attributable to high sodium intake decreased from 1990 to 2019, a significant increase in absolute burden occurred. Action is needed to accelerate the pace of sodium reduction, which would result in cost-effective and substantial benefits to global health. There is also a need to continue to improve the prevention of diseases associated with high sodium intake, such as cardiovascular disease, chronic kidney disease, and stomach cancer.

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Conflict of interest and funding disclosure

Authors declare that there is no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.numecd.2021.08.033.

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